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This is the fourteenth report on project EREP 108 and it covers the month of August 1974.

The final report on the hand-held photography aspects of the SKYLAB contract has been completed. A copy (without figures) is included for your information. Results of this report will be presented, along with other work on this project, at an invited session of the American Society of Photogrammetry's annual meeting next spring. A paper entitled: Satellite Photography of Eddies in the Gulf Loop Current by George A. Maul (NOAA-AOML), Dean R. Norris (NASA-JSC) and William R. Johnson (Lockheed-Houston), has been accepted for publication in Geophysical Research Letters for October 1974.

Data processing is progressing slowly, but will be expediated now that the ERTS final report is drafted and sent for review. Professor Gordon has continued his theoretical studies on scattering in the atmosphere and is preparing a paper on the work for Applied Optics. Hopefully we can critically test this work with SKYLAB data when it becomes available.

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An Assessment of the Potential Contributions to Oceanography from Skylab Visual Observations and Hand-Held Photography

by

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INTRODUCTION

For 84 days, the crew of Skylab 4 enjoyed the opportunity to observe the world's oceans from a unique vantage point. The breadth and frequency of their survey provides a valuable and distinct view of this subject in a science long limited to a few ships for huge oceans. The record of their observations gives us not only improved insight into the sea, but also insight into the possible utility for oceanography of men in space.

It is the intention here to examine that utility by considering some of the things learned from space observations thus far. This report will begin with a discussion of a few of the most interesting ocean photographs and visual observations made during the Skylab missions. Consideration of what can and cannot be done with these pictures has produced a set of recommendations the authors believe will optimize the information a man can gather in space. The report will discuss that optimization in light of possible alternative systems for gathering the same type of data.

OBSERVATIONS

Fig. 1 shows the Gulf of Nicoya on the Pacific coast of Costa Rica, photographed on January 28, at 1225 standard zone time (ZT). It is a prime example of a useful space photograph of the oceans because it shows fine detail and includes sufficient land for the water features to be positioned on a regular chart and measured. The ability to determine the geographical coordinates and the time of a photograph is an important criterion for a picture to be useful. Where positioning is not possible, a picture, while perhaps demonstrating the sort of things which can be seen from space, rarely lends itself to any usable interpretation.

The striking feature of Fig. 1 is the apparent internal wave field, organized into at least three distinct packets, which can be seen in the lower part of the photograph. These are interfacial waves which take place at density boundaries between layers within the water. When these waves are close enough to the surface they may manifest themselves as parallel "slicks" on the water, which move with the same velocity as the waves.

Surveys in this region show a density discontinuity at a depth of about 30 meters. Measurements off the photograph give a wavelength (λ) for the field of approximately 1000 m, with about 31 km between the fronts of the different packets. For a two-layer model:

$$C = \left[\frac{g}{k}\left(\frac{\rho-\rho'}{\rho \coth kh + \rho' \coth kh'}\right)\right]^{\frac{1}{2}}$$

where C = speed of the waves, ρ = density of the lower water layer, ρ' = density of the upper water layer, g = 9.8 ms $^{-2}$, h' = thickness of the upper water layer, h = thickness of the lower water layer, $k = 2\pi/\lambda$. In this case the equation gives a wave speed of 69 cms $^{-1}$, which falls in the range of theoretical expectations. Using this speed and the distance of 31 km between packets measured on the photograph, the time between passage of the packets is 12.5 hours. This time corresponds very closely to the interval of the semi-diurnal tide cycle dominant in this area, as shown by records from the tide station at Puntarenas. This supports the notion that internal waves play a dominant role in the dissipation of tidal energy, which affects the rotation of the earth.

Further examination of the wave fronts reveals that they are curvilinear features. The bottom topography in this region has a "U" shaped shoal extending to the southwest which causes the refraction pattern seen in the photograph. Thus the energy from the tide is transformed into internal waves which propagate into the coastal zone where their energy is dissipated in turbulent diffusion, causing the vertical mixing of the water.

Figs. 2 and 3 are consecutive pictures taken off South Africa on December 7, at about 1300 ZT. The important features are two large-scale eddies in the left central part of Fig. 2, and an apparent water boundary visible as a color change running through the center of Fig. 3. Fig. 4 represents the best fit of these features to a Chamberlin Trimetric projection. This fit is an approximation, because the distortion of the highly oblique Fig. 2, and the small amount of land in Fig. 3 make positioning difficult. Obliqueness in space photography involves major trade-offs between the relative ease of mapping near vertical pictures, and the greater coverage and interesting angles available in an oblique view. Inclusion of land for orientation, whenever possible, remains the most important factor, and obliqueness may be desirable where it is necessary to get sufficient land in the picture.

An eddy is shown on charts of oceanic sea-surface currents, with an anti-cyclonic rotation (see inset to Fig. 4), north of the subtropical convergence zone between the Westwind Drift and the current systems of the central South Atlantic. Data taken in 1925 by the Meteor Expedition were used to construct those charts, and very few hydrographic stations were available; this Skylab data suggests that this may indeed be a region where eddies are frequently formed. The color changes indicate that the apparent centers of the eddies contain water different from the outer portion of the circulation. Unfortunately, quantitative measurements from the photograph to try to determine water temperature and composition aren't possible.

The water boundary of Fig. 3 exhibits the meandering sometimes characteristic of current boundaries. From its position, it appears to be the subtropical convergence associated with the Agulhas Current. This current flows southwestward down the east coast of South Africa until it encounters the Westwind Drift zone off the Cape of Good Hope. Some idea of the flow possible in this region can be gained from the track, included in Fig. 4, of a free-drifting buoy which was deployed between July and October of 1973. The ability to plot the Agulhas Current and the eddies on a regular basis could be a boon to the large number of ships, particularly supertankers, which make passage around the Cape of Good Hope. Westbound ships like to make use of the current to gain extra speed at no cost, and eastbound ships avoid it so as not to be slowed.

The Skylab 4 crewmen remarked that the hand-held photography was often disappointing to them because the 70-millimeter photographs didn't reveal the detail or the vividness of their sightings. They felt that the multispectral photographic camera experiments (S190A) and, especially, the Earth Terrain Camera experiments (S190B) were more representative of visual clarity. For example, Carr remarked that the ocean had a fine texture to it, which to his eye resembled corduroy material. Only in examining the S190B photographs with a magnifier could he detect that common pattern, which is probably a manifestation of surface waves.

The crewmen remarked that they used the binoculars at least half of the time; this fact may explain their disappointment with the hand-held 70-millimeter photographs and the reason that the S190B product was much closer to the detail actually seen. Similarly, with a narrow field of view, less contrast is sacrificed because of atmospheric scattering. Thus many of the descriptions given were made while using binoculars, and the relatively wide field of view of the 70-millimeter camera, which was used without a viewfinder, did not reproduce the observation.

Figs. 5, 6, and 7 are examples of colored water that may be caused by plankton, which occurs where surface water is rich in life sustaining nutrients. In each of these cases the color outlines the boundary of water flow. Fig. 5, taken on December 19, at 1542 ZT, shows the confluence of the Falkland Current and the Brazil Current; Mar del Plata, Argentina is in the foreground. Fig. 6 is a discoloration in the Falkland Current, taken on December 25, at 1103 ZT. It is not certain if the reddish color is terrigenic or biogenic, but it is known that large patches of lobster krill can discolor the water in this fashion and are common here at this time of the year. It was totally unexpected that the Falkland Current would appear bright green as it flowed northwest from Cape Horn, past the Falkland Islands, and eventually east into the South Atlantic off the Rio del Plata. The Skylab 4 crewmen reported that the boundary of the warm Brazil Current and the cool Falkland Current could be followed visually for over 3500 kilometers, and that the two currents formed intertwining serpentine paths, yet never showed mixing across the boundary. The growth and separation of meanders and current rings have never been seen in this South Atlantic analog to the Gulf Stream-Labrador Current system. The combination of orbital ground-track convergences at 51° south latitude permitted repeated observations of the currents during January.

Unfortunately, there is not sufficient information to orient all the pictures to a common projection, so as to construct a time series of the current. Such a time series, with the detail afforded by these pictures, could be one of the most informative products of space photography. In addition, new observations by the crewmen of what appear to be plankton blooms may provide biological oceanographers with further insight into the spatial and temporal extent of these plankton blooms.

Fig. 7 was taken at about 1323 ZT, on December 7, in the South Pacific, east of New Zealand. The lower half of the picture shows a streaming event of light colored water in the center and more diffused patches to each side. Though there are no specifically named currents in this region, the apparent eddying and general configuration of the central band is indicative of current activity, and is probably associated with the subtropical convergence which passes between North Island and South Island, New Zealand.

Plankton blooming is one case where the color in space photographs can be used quantitatively, by measuring the ratio of blue transmission to that of green on the transparencies with a spectro-microdensitometer. These data, correlated with surface observations, may provide us with the knowledge to determine plankton concentrations from space. Plankton, the base link in the oceanic food chain, is a prime indicator of areas potentially rich in sea life; information concerning plankton distribution is important to fishermen and marine biologists.

Transmission ratios for Figs. 6 and 7 are given in Table 1; each value is the mean of several individual measurements from different locations in the appropriate water zone. The larger standard deviations are due to patchiness in the water. If other conditions affecting the upwelling radiance from the ocean are equal (sea state, sun glitter, oceanic particulates and atmospheric scatterers), these ratios can be evaluated in terms of chlorophyll-a concentrations. Thus if the photographs are calibrated in a few places, the isopleths of blue/green can be transformed into contours of pigment concentrations, which are proportional to phytoplankton populations.

Other measurements made from pictures taken by wide angle aerial lenses have revealed a vignetting problem which seriously affects the ratios. Where this problem exists, an adjustment curve must be obtained in order to rectify the numbers; this is done by obtaining values from a photograph of a uniform color field with the same lens. An example of such a curve is given in Fig. 8. All Skylab photographs measured thus far have been taken with a Hasselblad, using various lenses, and there is no indication of any serious vignetting effect thus far. It is a problem, however, that should be considered in future flights, and an adjustment curve for each lense-filter combination should be made prior to the flight.

Fig. 9 is an example of mesoscale ocean eddies observed in the sunglint of a vertical photograph taken of the Gulf of Mexico on August 4, at 1335 ZT. Ordinarily, sunglint is avoided in over-water photography because color information is lost in the specular reflection. The Skylab 4 crewmen, however, reported that a great deal of information could be found in the glitter patterns. These eddies are associated with the Loop Current in the eastern Gulf of Mexico, and their location has been correlated with the known position of this Gulf Stream-type flow. This represents not only the important discovery that such features can be seen in an otherwise rejected photographic technique, but also the promise of searching for other examples for a frequency-of-occurrence evaluation. In addition, air-sea interaction studies may be enhanced by studying sunglint patterns and relating them to the wind stress vector in the atmospheric boundary layer.

The photograph in Fig. 9 is partly stereographic because the next frame had 18% end-lap. This is the only example where positive identification of surface features could be made and isolated from clouds. Many potentially useful photographs have questionable value because a feature may be oceanic or atmospheric; stereo pairs or a stereo camera would eliminate many such doubts.

DISCUSSION

There are many examples of the usefulness of manned space vehicles to science, particularly in the area of flexibility of observation programs and routines. Communications between the scientists on the ground and the space observers can significantly improve the usefulness of space observations by leading to better site choices and techniques. The ability to voice record the human observations gives to the scenes a perspective they otherwise could not have. This perspective is valuable because of man's visual acuity and his ability to switch quickly between conducting a detailed scrutiny and taking a general large area survey.

Furthermore, the relative motion of the vehicle and the earth is a tremendous aid to depth perception; in fact, for the scientists one of the most valuable aspects of debriefing was watching the television tapes to learn how the earth is seen from orbit.

From the standpoint of oceanography, however, the space observations have not reached the full potential of their usefulness because many of the pictures cannot be geographically positioned. This limitation is critical as it prevents accumulation of any sort of time series, which, because most ocean features change relatively quickly, are important tools to understanding ocean dynamics. The ability to take very oblique shots, while sometimes a distinct advantage, also works against mapping ease. One possible approach to the problem of mapping is to try to match the photograph to weather satellite imagery. Attempts by the authors, using the standard archived product of the NOAA-2 weather satellite, have not been successful owing to the fairly low resolution of the satellite images and the time difference between observations by the satellite and the Skylab crew. Very high resolution instruments (VHRR) exist on the same NOAA satellite, however, and can be turned on if sufficient advance warning if given. The polar orbiting satellites are not as useful for this as the high-resolution sensors on geosynchronous vehicles because the time difference between each observation is critical when using clouds as common locators in manned photography and imagery. Because of the NOAA archiving procedure, it is recommended that SMS-GOES data at full resolution, to be stored on magnetic tape, be ordered <u>before</u> the ASTP mission. The documentation, awkward to use and occasionally incomplete, has been one of the main problems with the Skylab photographs. Documentation was in the form of hand and voice logging, and as the Skylab crew has attested, hampered activities in space as well as on the ground. The technology exists to annotate each frame automatically with information such as date and time as it is taken. This would relieve crewmen of much of their logging responsibilities and facilitate use of the photographs later on. Consideration should be given also to recording other numbers such as f/stop, shutter speed, magazine and frame number, and as much other pertinent information as possible.

In addition, the camera should use a zoom lens to eliminate lens changes, and should be single lens reflex. Ideally, the camera would include the functions of a pair of binoculars. Filters should be quick and easy to exchange, and the film advance should be motorized to facilitate stereo shots. Since good depth perception is important in photo interpretation, all space photography should be taken in stereo pairs. Vignetting curves should be obtained for all combinations of the lenses and filters, for uniform color fields at 455, 540 and 670 nanometers to conform with the appropriate Wratten filters. With few exceptions, 35 mm photography was not as interesting as the 70 mm and the crew apparently found the 35 mm Nikon harder to use. Having exchangable film backs or magazines would permit more flexible use of different film types for each photographic situation. There is considerable research today on developing films for oceanographic photography; specialized alternatives to a standard color film should be investigated.

The formidible ergonomics of such a photographic system may indicate that a very high resolution television system would be superior. A television operable, or at least viewable, in real time by scientists on the ground could give to those scientists the depth perception inherent in the spacecraft's motion and the sense of "being there" which simply can't be obtained from a photograph. The over-flights could be videotaped, and it should be easy to produce photographic copies of important scenes from the television image.

The crew of Skylab 4 found they spent several days learning to identify their location at any time over the earth. More intensive geographical training prior to flight should reduce the length of this orientation period. The experience of the Skylab 4 crewmen may be the most important link in such a training procedure, and could be their most important long term contribution to the space science effort. Crew training for future flights should include simulated identification of oceanic features at the same scale as those seen in orbit. This can be accomplished by flying aircraft missions that simulate the resolution and color observed from space (aircraft missions can be flown without the astronauts to gather the simulated data for later instruction sessions), and by reviewing photographs and television tapes from previous space flights.

One of the dominant aspects of oceanographic features is that they are in constant motion. Among the earth's dominant natural phenomena, only meteorological events occur more rapidly than oceanographic events; Gulf Stream features, for example, may shift position significantly in only one or two days. Because of these rapid, highly variable motions, an ocean observation needs to be one of a series to provide a clear picture of the dynamics involved. Identification of water types, plankton distribution and types, and other discernable parameters will become possible only if the observations are on a well calibrated, quantitative basis.

Oceanographic observations from space have a clear utility, in that they provide a much needed opportunity to survey the oceans on a scale and with a regularity which cannot be duplicated any other way. While the scientific usefulness of hand-held photography has a distinct role in reconnaissance, it cannot surpass the quantitative possibilities of a multispectral observation in a known altitude. Significantly, many of the most interesting ocean scenes were taken by the S190B, which produced very high resolution photographs in a vertical orientation. From the standpoint of long term oceanographic research from space, the pressing need is for quantitative observations that are capable of accurate geographical positioning, and concurrent ocean surface observations to correlate the data. Man, as the observation instrument, can significantly augment these needs by real-time interaction with earth-bound scientists in a coordinated effort of discovery and exploration.

LIST OF FIGURES

Figure 1: Internal wave packets in the Pacific Ocean off the coast of Costa Rica. The leading edge of each of three packets is identified by an arrow. Changes in apparent water color are due to specular return of sunglint due to changes in wave slopes, 70 mm photograph (SL4 - 142 - 4567).

Figure 2: Two large eddies off the southwest coast of South Africa are identified by arrows pointing towards the blue water in the center. These features are 200-300 kilometers in diameter and are probably anticyclonic. These eddies are sketched in figure 4. 35 mm photograph (SL4 - 196 - 7387).

Figure 3: Boundary between water masses off South Africa. This color difference probably delimits the blue waters of the Agulhas Current, which has a tropical origin in the Indian Ocean, and the Westwind Drift of subantarctic origin. These wave-like features may grow and detach to form the eddies seen in figure 2, which was taken during the same overflight. 35 mm photograph (SL4 - 196 - 7389).

Figure 4: Sketch of the South Atlantic off Cape of Good Hope showing the features photographed in figures 2 and 3. The buoy track by Stavropoulos and Duncan in the Agulhas Current was made by satellite tracking, and serves to give representative velocities. The boundary labeled from figure 3 is probably the subtropical convergence. Inset is a schematic map of surface currents in the South Atlantic Ocean; the solid line is the subtropical convergence zone.

Figure 5: East looking view from Mar del Plata, Argentina of the confluence of the north flowing Falkland Current and the south flowing Brazil Current. The light green streaming probably marks the right-hand edge (facing down-stream) of the currents and hence is the inshore boundary of the Brazil Current and the offshore edge of the Falkland Current. 70 mm photograph (SL4 -137 - 3690).

Figure 6: Near vertical photograph of reddish discoloration imbedded in the Falkland Current; probably biogenic material (arrow). The offshore edge of the current appears as a bright green lineation, then a dark blue zone separating the green from a lighter blue region which is dominated by eddies approximately 15-20 kilometers in diameter. 70 mm photograph (SL4 - 137 - 3721).

Figure 7: High oblique view east of New Zealand. The light blue meandering flow is near the historical position of the subtropical convergence zone and demonstrates horizontal shear flow instability 70 mm photograph (SL4 - 136 - 3446).

Figure 8: Example of vignetting causing significant changes in the blue/green ratio of transmitted light measured over a uniformly blue ocean target. This result from an aircraft transparency, shows that a significant correction may be necessary when using blue/green transmission ratios to assess the chlorophyll concentration in water (from S. Baig, personal communication).

Figure 9: Vertical photograph in the eastern Gulf of Mexico showing eddies 12-32 kilometers in diameter observed in the sunglint pattern. These shear flow instabilities have no color associated with them because the eddies are in the main body of the Gulf Loop Current. The serpentine feature (arrow) is probably an oil slick since this is along the main shipping route to New Orleans. 70 mm photograph (SL3 - 22 - 124).

Figure 10: Oblique photograph of the Falkland Current; computer enhanced inset is the NOAA-2 scanning radiometer archived visible image taken the same day. Correlation of the cloud feature in the photograph with the image is not possible for several reasons: image ground resolution not sufficient, insufficient field of view in photograph, and time lag between observations. Without ability to locate each ocean photograph, the value is significantly diminished. 70 mm photograph (SL4 - 143 - 4610).

TABLE 1

Scene: SL4 - 136 - 3447

Region	Ratio
Front	2.33 ± 0.07
Surrounding water	3.13 ± 0.51

Scene: SL4 - 137 - 3721

Region	Ratio
Front	1.57 ± 0.14
Surrounding water	2.33 ± 0.02
Plankton Bloom	2.29 ± 0.06

Note: The percent transmission is measured with a microdensitometer which uses an irradiance receptor. White light is passed through the filter, then the transparency for measurement.

Blue Filter: Wratten No. 94 (455 nm)

Green Filter: Wratten No. 93 (540 nm)